

# The W UMa binaries USNO-A2.0 1350-17365531, V471 Cas, V479 Lac and V560 Lac: light curve solutions and global parameters based on *Gaia* distances

Diana P. Kjurkchieva<sup>1</sup>, Velimir A. Popov<sup>1</sup>, Yordanka Eneva<sup>1,2</sup> and Nikola I. Petrov<sup>3</sup>

<sup>1</sup> Department of Physics and Astronomy, Shumen University, 9700 Shumen, Bulgaria; [d.kjurkchieva@shu.bg](mailto:d.kjurkchieva@shu.bg)

<sup>2</sup> Medical University, Varna, 84 Tcar Osvoboditel str., Bulgaria

<sup>3</sup> Institute of Astronomy and NAO, Bulgarian Academy of Sciences, 72 Tsarigradsko Shose Blvd., 1784 Sofia, Bulgaria

Received 2018 August 9; accepted 2018 September 20

**Abstract** We present photometric observations in Sloan filters  $g'$ ,  $i'$  of the eclipsing W UMa stars USNO-A2.0 1350-17365531, V471 Cas, V479 Lac and V560 Lac. The sinusoidal-like  $O - C$  diagram of V471 Cas indicates the presence of a third body with mass  $0.12 M_{\odot}$  (a red dwarf) at distance  $897 R_{\odot}$ . The  $O - C$  diagram of V479 Lac reveals a period decrease of  $dP/dt = -1.69 \times 10^{-6} \text{ d yr}^{-1}$ . The results of the light curve solutions are: (i) the targets are overcontact binaries with small fill-out factors; (ii) their components are F–K stars, comparable in size, whose temperature differences are below 80 K; (iii) all targets undergo partial eclipses and to limit the possible mass ratios we carried out two-step  $q$ -search analysis. The target global parameters (luminosities, radii, masses) were obtained on the basis of their *Gaia* distances and the results of our light curve solutions. The obtained total mass of V560 Lac turns out to be smaller than the lower mass limit for presently known W UMa binaries of  $1.0 - 1.2 M_{\odot}$ , i.e. this target is a peculiar overcontact system.

**Key words:** binaries: close — binaries: eclipsing — methods: data analysis — stars: fundamental parameters — stars: individual (USNO-A2.0 1350-17365531, V471 Cas, V479 Lac, V560 Lac)

## 1 INTRODUCTION

High-precision positions in the Hertzsprung–Russell diagram of stars with known surface abundances, provided by *Hipparcos* and by high-resolution spectroscopy, have revealed discrepancies between observations and predictions of standard stellar models (Perryman et al. 1995). Hence, although the fundamental principles of stellar evolution are well known, there are some aspects related to the theories of evolution and stellar interiors which require further improvement. These problems need precise fundamental parameters of stars in different stages of their evolution.

Eclipsing binary systems are the most important sources of such information, especially the numerous W UMa-type binaries consisting of two main sequence stars embedded in a common convective photosphere (Lucy 1968a,b).

The determination of global parameters for W UMa systems is difficult because the photometric mass ratio of most of them, which undergo partial eclipses, is

poorly estimated (Rucinski 2001, Terrell & Wilson 2005). Moreover, their spectral mass ratios are not precise due to the highly broadened and blended spectral lines of the components (Frasca et al. 2000; Bilir et al. 2005; Dall & Schmidtbreick 2005).

The *Gaia* mission (Gaia Collaboration et al. 2018) has opened new horizons in the study of W UMa stars because it provides unprecedented parallax measurements of about one billion stars in our Galaxy, enabling high-precision determination of the global parameters for many eclipsing binary systems observed from the ground.

This paper presents photometric observations of the short-period W UMa-type systems USNO-A2.0 1350-17365531 (hereafter referred to as USNO 1350), V471 Cas, V479 Lac and V560 Lac.

Table 1 presents information on their coordinates and variability from the VSX database. The goal of our study is to determine their parameters by light curve solutions and *Gaia* distances as well as to search for period changes.

**Table 1** Parameters of the Targets from the VSX Database

Target	RA	Dec	mag	ampl	$P$	Type	Reference
USNO 1350	22 48 35.91	+50 49 06.4	14.48(CR)	0.48	0.26638	EW	Lapukhin et al. 2014
V471 Cas	01 32 20.48	+55 12 19.8	14.1(p)	0.5	0.335998	EW/KW	Hoffmeister 1966
V479 Lac	22 52 50.69	+35 58 56.5	12.2(R)	0.70	0.34575	EW	Khruslov 2008
V560 Lac	22 48 32.56	+50 49 35.4	14.34(CR)	0.64	0.2722	EW	Lapukhin et al. 2013

**Table 2** Journal of Our Photometric Observations

Star	Date	Exposure (s)	Number	Error
USNO 1350	2017 Oct 9	240, 240	21, 21	0.017, 0.014
	2017 Oct 10	240, 240	37, 37	0.030, 0.026
	2017 Oct 11	240, 240	41, 41	0.011, 0.012
V471 Cas	2017 Nov 22	150, 240	86, 86	0.006, 0.007
	2017 Nov 23	150, 240	81, 81	0.005, 0.006
V479 Lac	2017 Oct 12	60, 120	140, 140	0.005, 0.005
	2017 Oct 13	60, 120	62, 62	0.006, 0.007
	2017 Oct 14	60, 120	137, 137	0.010, 0.010
V560 Lac	2017 Oct 9	240, 240	21, 21	0.014, 0.013
	2017 Oct 10	240, 240	39, 39	0.022, 0.027
	2017 Oct 11	240, 240	41, 41	0.009, 0.012

## 2 OBSERVATIONS

Our CCD photometric observations of the targets in Sloan  $g'$ ,  $i'$  bands were carried out with the 30-cm Ritchey-Chretien Astrograph (located in the *IRIDA South* dome) using an ATIK 4000M CCD camera. Information about our observations is presented in Table 2.

The photometric data were reduced by AIP4WIN2.0 (Berry & Burnell 2005). Aperture ensemble photometry was performed with the software VPHOT using more than six standard stars (Table 3) in the observed field, the coordinates of which were taken from the UCAC4 catalog (Zacharias et al. 2013) and their magnitudes from APASS DR9.

## 3 LIGHT CURVE SOLUTIONS

We carried out modeling of our data using the PHOEBE package (Prša & Zwitter 2005; Prsa et al. 2011; Prša et al. 2016) which is based on the Wilson-Devinney (WD) code (Wilson & Devinney 1971; Wilson 1979, 1993). It allows simultaneous modeling of photometric data in a number of filters and provides a graphical user interface.

The observational data (Fig. 1) show that the targets are overcontact systems and we modeled them using the corresponding mode “Overcontact binary not in thermal contact” of PHOEBE.

Table 4 presents the target temperatures  $T_m^{ci}$  determined by the observed de-reddened color indices ( $g' - i'$ ) at quadratures and the relation of Covey et al. (2007),

as well as their temperatures  $T_m^G$  from *Gaia* DR2 (Gaia Collaboration et al. 2018) and  $T_m^L$  from LAMOST (Luo et al. 2015). The differences in the temperature values may be due, at least partially, to the different (inappropriate) phase of measurements of *Gaia* and LAMOST. The last column reveals the adopted  $T_m$  values in the procedure utilized for the light curve solution.

We fixed the primary temperature  $T_1 = T_m$  and searched for the best fit varying initial epoch  $T_0$ , period  $P$ , secondary temperature  $T_2$ , mass ratio  $q$ , inclination  $i$  and potential  $\Omega$ . We adopted coefficients of gravity brightening 0.32 and reflection 0.5 appropriate for late-type stars (Table 4). The limb-darkening coefficients were interpolated according to the tables of van Hamme (1993). In order to reproduce the light curve distortions, we used cool spots and varied their parameters (longitude  $\lambda$ , latitude  $\beta$ , angular size  $\alpha$  and temperature factor  $\kappa$ ). Hence, each spot introduces four new parameters which cannot be unambiguously determined (except for spot longitude). That is why we applied the following considerations to reduce the spot parameters: (i) Due to lack of additional knowledge (for instance spectral or polarimetric data) the spots were put on the primary (hotter) component, but the same result could be reached by placing the spot on the secondary component with bigger temperature contrast; (ii) We used equatorial spots, i.e. the spot latitude was fixed; (iii) The temperature contrast  $\kappa = (T_{ph} - T_{sp})/T_{ph}$  was varied in the range 0.8–0.9 appropriate for the component temperature (Berdyugina 2005).

**Table 3** List of Standard Stars

Label	Star ID	RA	Dec	$g'$	$i'$
Target	USNO 1350	22 48 35.91	+50 49 06.4	15.17	13.91
Chk	UCAC4 705-109759	22 48 35.25	+50 49 45.32	14.260	13.042
C1	UCAC4 705-109766	22 48 37.22	+50 53 39.86	12.768	11.229
C2	UCAC4 705-109796	22 48 46.35	+50 48 49.30	13.931	13.047
C3	UCAC4 705-109827	22 48 55.60	+50 49 38.22	13.099	12.509
C4	UCAC4 705-109708	22 48 19.49	+50 49 49.20	13.885	13.275
C5	UCAC4 705-109721	22 48 23.35	+50 49 22.84	14.237	13.746
C6	UCAC4 704-108193	22 48 01.25	+50 47 31.75	13.654	13.005
C7	UCAC4 704-108347	22 48 40.68	+50 47 38.84	13.185	12.562
C8	UCAC4 705-109878	22 49 09.62	+50 48 21.86	12.863	12.240
Target	V471 Cas	01 32 20.48	+55 12 19.8	13.87	13.07
Chk	UCAC4 727-012640	01 32 11.74	+55 13 34.01	14.255	13.505
C1	UCAC4 727-012714	01 32 39.00	+55 15 08.04	13.768	13.253
C2	UCAC4 727-012652	01 32 17.81	+55 14 52.41	13.096	12.673
C3	UCAC4 727-012622	01 32 02.18	+55 14 33.01	13.107	12.420
C4	UCAC4 727-012552	01 31 37.73	+55 14 17.12	13.275	12.682
C5	UCAC4 726-012990	01 32 44.12	+55 10 24.72	14.484	12.894
C6	UCAC4 726-012935	01 32 18.10	+55 09 03.67	14.092	12.411
C7	UCAC4 727-012662	01 32 21.12	+55 18 24.56	14.185	11.800
C8	UCAC4 727-012588	01 31 49.76	+55 13 56.00	13.789	13.229
C9	UCAC4 727-012623	01 32 02.28	+55 13 20.10	12.316	11.625
C10	UCAC4 726-012820	01 31 40.78	+55 11 26.78	14.233	13.466
Target	V479 Lac	22 52 50.69	+35 58 56.5	12.49	11.75
Chk	UCAC4 630-129893	22 52 59.78	+35 58 32.07	13.770	12.215
C1	UCAC4 630-129875	22 52 43.78	+35 53 55.03	12.034	11.603
C2	UCAC4 630-129912	22 53 19.06	+35 56 53.76	13.762	13.257
C3	UCAC4 630-129921	22 53 26.62	+35 59 53.33	13.413	12.547
C4	UCAC4 631-132559	22 52 30.81	+36 02 51.51	12.757	12.171
C5	UCAC4 631-132585	22 52 54.16	+36 00 31.90	11.904	11.351
C6	UCAC4 631-132557	22 52 29.70	+36 00 15.27	13.990	13.333
Target	V560 Lac	22 48 32.56	+50 49 35.4	14.90	13.89
Chk	UCAC4 705-109759	22 48 35.25	+50 49 45.32	14.260	13.042
C1	UCAC4 705-109766	22 48 37.22	+50 53 39.86	12.768	11.229
C2	UCAC4 705-109796	22 48 46.35	+50 48 49.30	13.931	13.047
C3	UCAC4 705-109827	22 48 55.60	+50 49 38.22	13.099	12.509
C4	UCAC4 705-109708	22 48 19.49	+50 49 49.20	13.885	13.275
C5	UCAC4 705-109721	22 48 23.35	+50 49 22.84	14.237	13.746
C6	UCAC4 704-108193	22 48 01.25	+50 47 31.75	13.654	13.005
C7	UCAC4 704-108347	22 48 40.68	+50 47 38.84	13.185	12.562
C8	UCAC4 705-109878	22 49 09.62	+50 48 21.86	12.863	12.240

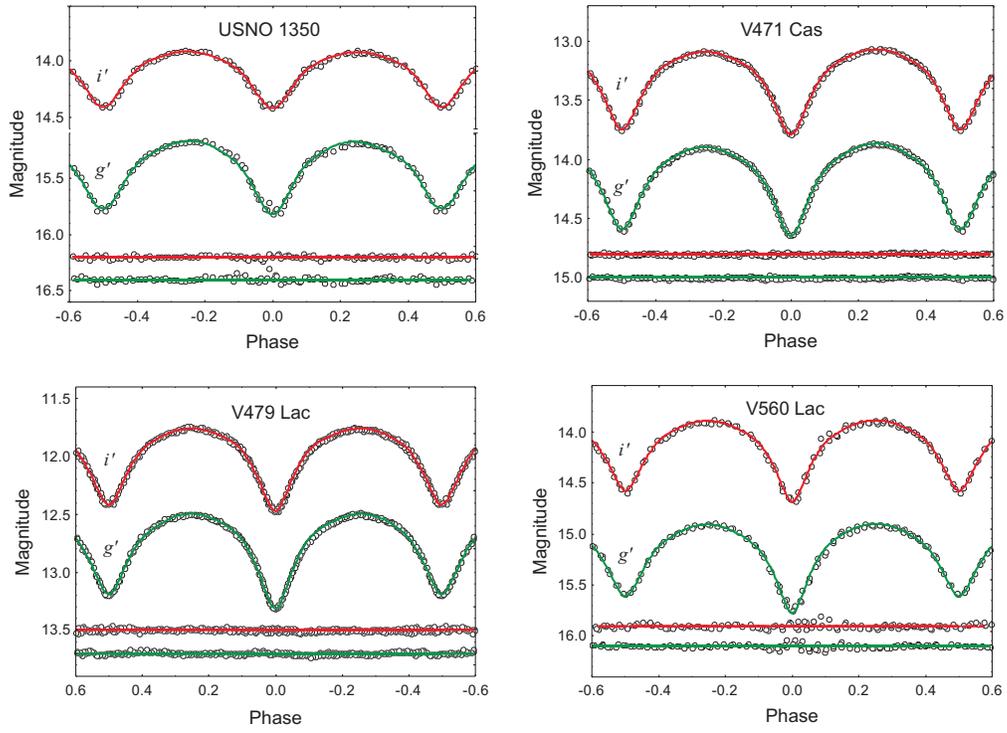
The eclipses of all targets do not contain a flat bottom (Fig. 1) which indicates partial eclipses. Hence, their photometric mass ratios are poorly determined (Rucinski 2001; Terrell & Wilson 2005) and require  $q$ -search analysis. Firstly, we varied the mass ratio in a wide interval, from 0.1 to 10.0, to obtain the global minimum of the  $q$ -search curves (Fig. 2). In order to further limit the possible mass ratios, we mapped the  $\chi^2$  dependence on  $q$  (for values within the global minimum) and orbital inclination  $i$

(Fig. 3). The obtained values of  $q$  and  $i$  were used in the last stage of the light curve solution.

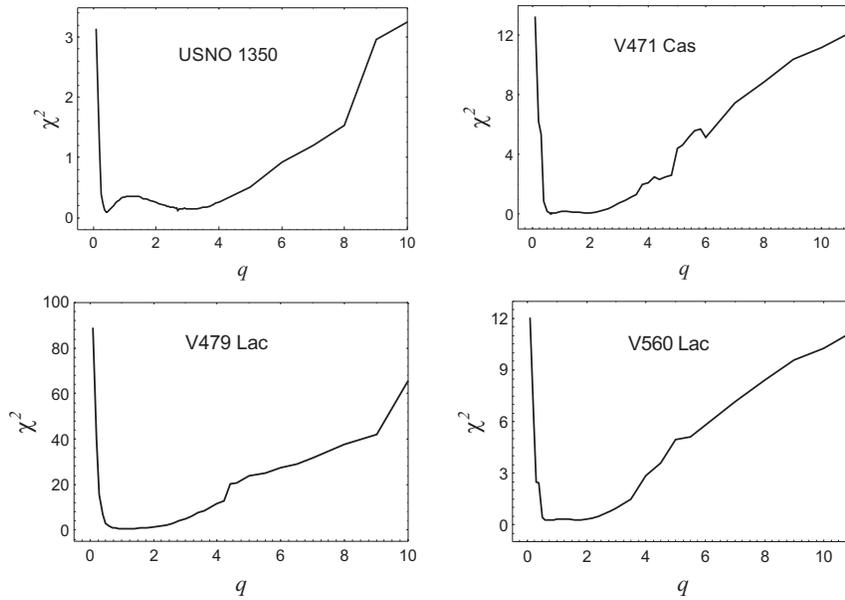
After reaching the best light curve solution, we adjusted the stellar temperatures  $T_1$  and  $T_2$  around the value  $T_m$  by the formulae (Kjurkchieva & Vasileva 2015)

$$T_1^f = T_m + \frac{c\Delta T}{c+1}, \quad T_2^f = T_1^f - \Delta T, \quad (1)$$

where the quantities  $c = l_2/l_1$  (the ratio of the relative luminosities of the stellar components) and  $\Delta T = T_m - T_2$  are determined from the PHOEBE solution.



**Fig. 1** Top of each panel: the folded light curves and their fits; Bottom: the corresponding residuals (shifted vertically by different amounts to save space).

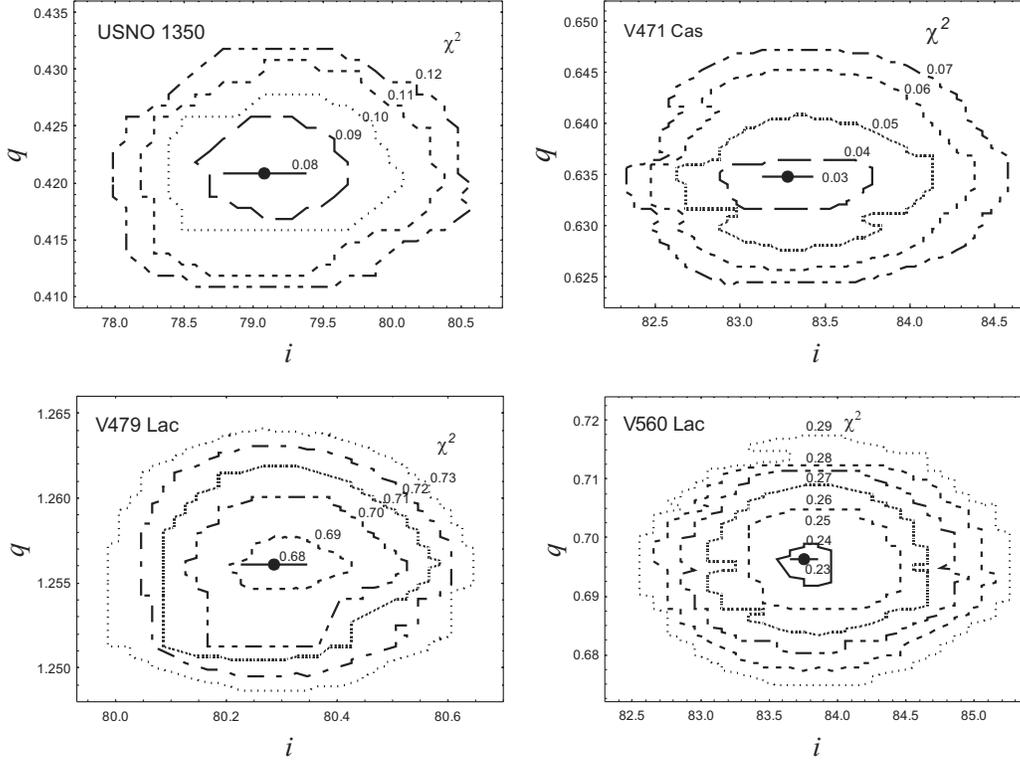


**Fig. 2**  $q$ -search curves for the four targets.

The last fitting procedure was carried out for fixed  $T_1^f$  and  $T_2^f$  and corresponding limb-darkening coefficients in order to obtain the final and self-consistent solution.

Table 5 contains the final values of the fitted stellar parameters and their uncertainties while Table 6 lists the cal-

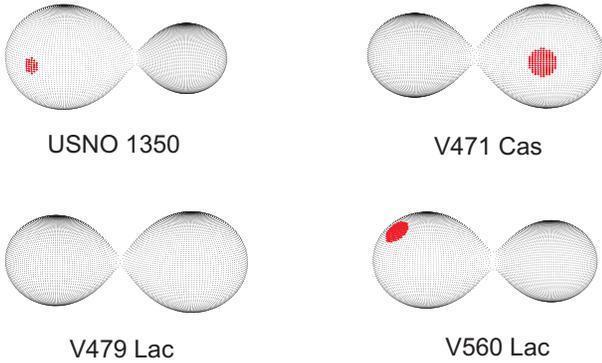
culated parameters: relative stellar radii  $r_{1,2}$ ; fill-out factor  $f$ ; ratio of relative stellar luminosities  $l_2/l_1$ . Their errors are determined from the uncertainties of the fitted parameters used for their calculation.



**Fig. 3** The  $\chi^2$  dependencies on mass ratio  $q$  and inclination  $i$ : the different isolines circumscribe the areas whose normalized  $\chi^2$  are smaller than the marked values; the circle corresponds to the minimum of  $\chi^2$ .

**Table 4** Target Temperatures

Target	$T_m^{ci}$	$T_m^G$	$T_m^L$	$T_m$
USNO 1350	5140	5095	–	5140
V471 Cas	6000	5347	–	6000
V479 Lac	5680	5361	6220	5680
V560 Lac	5650	5000	–	5650



**Fig. 4** Three-dimensional configurations of the targets made using Binary Maker 3 by Bradstreet & Steelman (2002).

Synthetic curves corresponding to the parameters of our light curve solutions are shown in Figure 1 as con-

tinuous lines while Figure 4 exhibits the target three-dimensional configurations.

#### 4 GLOBAL PARAMETERS

The target global parameters (Table 7) were calculated using the following procedure.

- (1) We determined absolute target magnitude  $M_V$  from the *Gaia* distance  $d$  (Bailer-Jones et al. 2018) and target magnitude  $V$  (corrected for extinction) by the formula for the distance modulus. The absolute target magnitude  $M_{bol}$  was calculated from  $M_V$  and the bolometric correction corresponding to the target temperature. Then, the absolute target luminosity  $L$  was obtained.
- (2) PHOEBE yields bolometric magnitudes of the two components  $M_{bol}^i$  in conditional units as output pa-

**Table 5** Fitted Parameters of the Best Light Curve Solutions

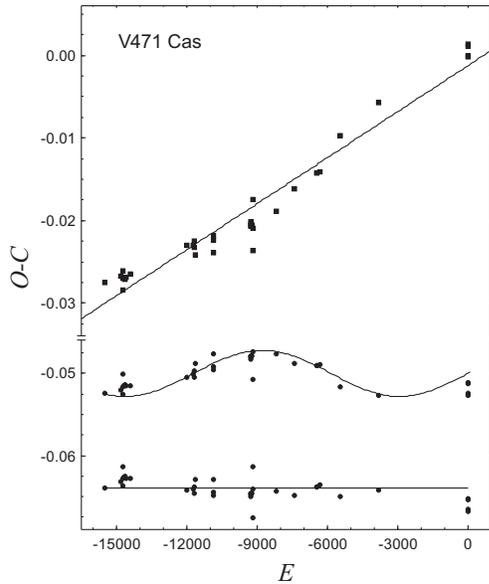
Star	$T_0$ (d)	$P$ (d)	$i$ ( $^\circ$ )	$q$	$T_2$ (K)	$\Omega$	$\beta$ ( $^\circ$ )	$\lambda$ ( $^\circ$ )	$\alpha$ ( $^\circ$ )	$\kappa$
USNO 1350	8037.514889(0.00024)	0.2663764	79.08(1.7)	0.421(0.07)	5090(40)	2.70(0.2)	90	238(1)	8(1)	0.89(1)
V471 Cas	8080.254983(0.0004)	0.40093526	83.28(0.5)	0.635(0.04)	5940(30)	3.098(0.07)	90	90(1)	15(1)	0.85(1)
V479 Lac	8039.299724(0.00012)	0.3457586(3)	80.37(0.5)	1.256(0.04)	5620(20)	4.141(0.05)				
V560 Lac	8038.60221(0.00012)	0.2722467(3)	82.03(2.4)	0.697(0.09)	5575(40)	3.199(0.2)	50	220(1)	15(1)	0.90(1)

**Table 6** Calculated Parameters

Star	$T_1^f$	$T_2^f$	$r_1$	$r_2$	$f$	$l_2/l_1$
USNO 1350	5155(38)	5104(91)	0.462(26)	0.312(24)	0.077	0.436
V471 Cas	5975(29)	6035(69)	0.427(6)	0.347(9)	0.078	0.692
V479 Lac	5713(22)	5652(19)	0.362(9)	0.402(9)	0.026	1.180
V560 Lac	5680(22)	5604(19)	0.420(9)	0.356(9)	0.095	0.681

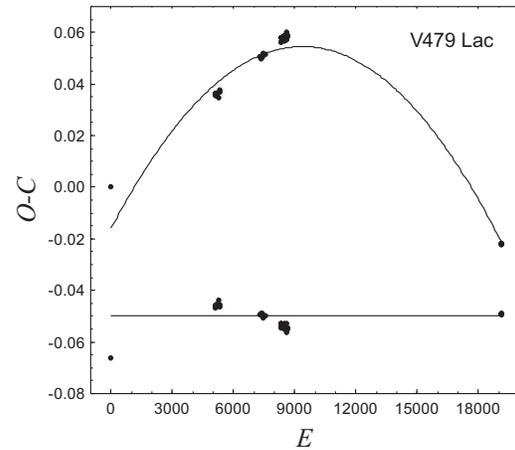
**Table 7** Global Parameters

Target	$d$ (pc)	$M_{\text{bol}}$	$L$ ( $L_\odot$ )	$L_1$ ( $L_\odot$ )	$L_2$ ( $L_\odot$ )	$R_1$ ( $R_\odot$ )	$R_2$ ( $R_\odot$ )	$a$ ( $R_\odot$ )	$M$ ( $M_\odot$ )	$M_1$ ( $M_\odot$ )	$M_2$ ( $M_\odot$ )
USNO 1350	629	5.177	0.681	0.474	0.207	0.866	0.583	1.86	1.233	0.868	0.365
V471 Cas	754	4.063	1.900	1.123	0.777	0.992	0.808	2.33	1.054	0.645	0.410
V479 Lac	370	4.159	1.739	0.798	0.942	0.914	1.015	2.52	1.803	0.799	1.004
V560 Lac	667	5.174	0.683	0.405	0.277	0.660	0.560	1.57	0.703	0.414	0.289



**Fig. 5** *Top panel:*  $O - C$  data for V471 Cas and their linear fit; *Middle panel:*  $O - C$  data minus linear fit (shifted vertically); *Bottom panel:* residuals ( $O - C$  data minus linear and sinusoidal fit, shifted vertically).

rameters (if there are no radial velocity curves), but their difference  $M_{\text{bol}}^2 - M_{\text{bol}}^1$  determines the true luminosity ratio  $l_2/l_1 = L_2/L_1$ . Its value and that of  $L$  allow us to calculate  $L_1$  and  $L_2$ .



**Fig. 6** *Top panel:*  $O - C$  data for V479 Lac and their quadratic fit; *Bottom panel:* residuals ( $O - C$  data minus quadratic fit, shifted vertically).

- (3) The absolute component radii  $R_i$  were estimated from their luminosities  $L_i$  and temperatures  $T_i$  (adopting black-body emission).
- (4) The absolute and relative component radii were used to obtain the orbital axis  $a$ .
- (5) The total masses of the targets  $M$  were calculated using Kepler's third law from the period  $P$  and orbital

axis  $a$ . Then, the component masses  $M_i$  were obtained from  $M$  and mass ratio  $q$ .

Thus, the *Gaia* distances and the foregoing standard procedure for determination of global parameters of eclipsing binaries supersede all the old empirical relations (Rucinski 2004; Gettel et al. 2006, etc.) related to this work.

## 5 ANALYSIS OF THE RESULTS AND CONCLUSIONS

The main results from our study of the W UMa-type binaries USNO 1350, V471 Cas, V479 Lac and V560 Lac are as follows:

- (1) Initial epochs for the four targets were determined (Table 5) and their periods were improved.
- (2) Our observations confirmed the conclusion of Liu & Tan (1991) that the orbital period of V471 Cas is not 0.335998 d (Table 1) but around 0.4 d. Liu & Tan (1991) obtained 0.405356(22) d.
- (3) Besides our observations, we found photometric data of V471 Cas and V479 Lac from the SWASP database and determined the times of light minima. Moreover, we used the available times of light minima for V471 Cas published in IBVS (Dvorak 2005; Hubscher 2005, 2011, 2014; Hubscher et al. 2005, 2006; Nelson 2008; Diethelm 2009, 2010, 2011, 2012).

The  $O - C$  diagram of V471 Cas contains 34 times of light minima (Fig. 5) which cover around 17 yr. We excluded the times of light minima obtained by Liu & Tan (1991) because their observations are photoelectric and have low time resolution. The  $O - C$  diagram shows sinusoidal variations superposed on a linear increase. The linear fit of the  $O - C$  diagram allowed us to improve the mean period of V471 Cas to 0.4009371165 d. The sinusoidal curve has a period of 12.8 yr and amplitude of 242 seconds. It implies the presence of a third body with mass of  $0.12 M_{\odot}$  (a possible red dwarf) orbiting the binary at distance  $897 R_{\odot}$ . Future observations would be able to refine these parameters.

The  $O - C$  diagram of V479 Lac with 41 times of light minima (Fig. 6) which cover around 18 yr reveals a period decrease of  $dP/dt = -1.69 \times 10^{-6} \text{ d yr}^{-1}$ .

- (4) The  $BV$  light curve solution of V471 Cas by Liu & Tan (1991) gives parameter values of V471 Cas:  $q = 0.595$ ;  $i = 83.29^{\circ}$ ;  $T_1 = 5660 \text{ K}$ ,  $T_2 = 5636 \text{ K}$ ;  $\Omega = 2.986$ ;  $r_1 = 0.44$ ;  $r_2 = 0.34$ . These values are within the errors of ours, excluding component temperatures which are both lower than ours by around 300 K.

- (5) All targets are slightly overcontact binaries with fillout factors up to 0.1.
- (6) All targets undergo partial eclipses. We carried out a two-step  $q$ -search analysis to limit their possible mass ratios.
- (7) The components of the targets are F–K stars. Their temperature differences are inconsiderable, below 80 K (Table 6).
- (8) The light curve distortions of USNO 1350, V471 Cas and V560 Lac were reproduced by cool spots on their primaries. Summarizing the optical, X-ray, UV, IR and radio observations, Dryomova & Svechnikov (2006) concluded that contact W UMa-systems have a highly variable corona, whose appearance and heating mechanism presuppose the presence of a magnetic field generated by a dynamo mechanism in differentially rotating convective layers. An indirect confirmation of the existence of magnetic fields in these late-type stars is their spotted activity.
- (9) The differences in the component temperatures (Table 6) are too small to determine the subtype, W or A, of our targets.
- (10) The components of all targets are comparable in size (Table 6). This is the reason for the partial eclipses, even with their high orbital inclinations.
- (11) The *Gaia* DR2 distances of the targets as well as the results of our light curve solutions allowed us to estimate the global parameters of USNO 1350, V471 Cas, V479 Lac and V560 Lac.
- (12) The obtained total mass  $0.745 M_{\odot}$  of V560 Lac is smaller than the lower mass limit for presently known contact binaries of  $1.0 - 1.2 M_{\odot}$  (Stepien 2006). This signifies considerable mass loss and implies a late evolutionary stage. Possible mechanisms could be: (i) prolonged intensive mass loss from the binary during the semidetached phase; (ii) sporadic mass losses during some burst-like events. The low mass makes V560 Lac a peculiar member of W UMa binaries. Its future study may shed additional light on the evolution of these systems.

The determined masses, radii and luminosities of the target components represent the main contribution of the paper because they could be used as tests for stellar models of W UMa-type binaries.

**Acknowledgements** This work was supported partly by project DN08/20 of the Scientific Foundation of the Bulgarian Ministry of Education and Science as well as by project RD 08-142 of Shumen University. The

research was carried out with the support of the private IRIDA Observatory operated remotely ([www.irida-observatory.org](http://www.irida-observatory.org)). The authors are very grateful to the anonymous referee for valuable notes and recommendations.

This paper makes use of the SIMBAD database, VizieR service and Aladin previewer operated at CDS, Strasbourg, France, and NASA's Astrophysics Data System Abstract Service.

This work has made use of data from the European Space Agency (ESA) mission *Gaia* (<https://www.cosmos.esa.int/gaia>), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC, <https://www.cosmos.esa.int/web/gaia/dpac/consortium>). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement.

This paper makes use of data from DR1 of WASP as provided by the WASP consortium, and the computing and storage facilities at the CERIT Scientific Cloud, reg. no. CZ.1.05/3.2.00/08.0144 which is operated by Masaryk University, Czech Republic.

## References

- Bailer-Jones, C. A. L., Rybizki, J., Fouesneau, M., Mantelet, G., & Andrae, R. 2018, *AJ*, 156, 58
- Berdugina, S., 2005, *Living Reviews in Solar Physics*, 2, 8
- Berry, R., & Burnell, J. 2005, *The Handbook of Astronomical Image Processing* (2nd edn. VA: Willmann-Bell)
- Bilir, S., Karataş, Y., Demircan, O., & Eker, Z. 2005, *MNRAS*, 357, 497
- Bradstreet, D. H., & Steelman, D. P. 2002, in *Bulletin of the American Astronomical Society*, 34, American Astronomical Society Meeting Abstracts, 1224 (eid: 75.02)
- Covey, K. R., Ivezić, Ž., Schlegel, D., et al. 2007, *AJ*, 134, 2398
- Dall, T. H., & Schmidtbreick, L. 2005, *A&A*, 429, 625
- Diethelm, R. 2009, *Information Bulletin on Variable Stars*, 5871
- Diethelm, R. 2010, *Information Bulletin on Variable Stars*, 5920
- Diethelm, R. 2011, *Information Bulletin on Variable Stars*, 5960
- Diethelm, R. 2012, *Information Bulletin on Variable Stars*, 6011
- Dryomova, G. N., & Svechnikov, M. A. 2006, *Astrophysics*, 49, 358
- Dvorak, S. W. 2005, *Information Bulletin on Variable Stars*, 5603
- Frasca, A., Marino, G., Catalano, S., & Marilli, E. 2000, *A&A*, 358, 1007
- Gaia Collaboration, Brown, A. G. A., Vallenari, A., et al. 2018, *A&A*, 616, A1
- Gettel, S. J., Geske, M. T., & McKay, T. A. 2006, *AJ*, 131, 621
- Hoffmeister, C. 1966, *Astronomische Nachrichten*, 289, 139
- Hubscher, J. 2005, *Information Bulletin on Variable Stars*, 5643
- Hubscher, J. 2011, *Information Bulletin on Variable Stars*, 5984
- Hubscher, J. 2014, *Information Bulletin on Variable Stars*, 6118
- Hubscher, J., Paschke, A., & Walter, F. 2005, *Information Bulletin on Variable Stars*, 5657
- Hubscher, J., Paschke, A., & Walter, F. 2006, *Information Bulletin on Variable Stars*, 5731
- Khruslov, A. V. 2008, *Peremennye Zvezdy Prilozhenie*, 8
- Kjurkchieva, D., & Vasileva, D. 2015, *PASA*, 32, e023
- Lapukhin, E. G., Veselkov, S. A., & Zubareva, A. M. 2013, *Peremennye Zvezdy Prilozhenie*, 13, 12
- Lapukhin, E. G., Veselkov, S. A., Zubareva, A. M., Starovoi, E. D., & Kolbasina, I. V. 2014, *Peremennye Zvezdy Prilozhenie*, 14, 11
- Liu, X., & Tan, H. 1991, *Ap&SS*, 183, 237
- Lucy, L. B. 1968a, *ApJ*, 153, 877
- Lucy, L. B. 1968b, *ApJ*, 151, 1123
- Luo, A.-L., Zhao, Y.-H., Zhao, G., et al. 2015, *RAA (Research in Astronomy and Astrophysics)*, 15, 1095
- Nelson, R. H. 2008, *Information Bulletin on Variable Stars*, 5820
- Perryman, M. A. C., Lindegren, L., Kovalevsky, J., et al. 1995, *A&A*, 304, 69
- Prša, A., & Zwitter, T. 2005, *ApJ*, 628, 426
- Prsa, A., Matijevic, G., Latkovic, O., Vilardell, F., & Wils, P. 2011, *PHOEBE: PHysics Of Eclipsing BinariEs*, *Astrophysics Source Code Library*, ascl:1106.002
- Prša, A., Conroy, K. E., Horvat, M., et al. 2016, *ApJS*, 227, 29
- Rucinski, S. M. 2001, *AJ*, 122, 1007
- Rucinski, S. M. 2004, *New Astron. Rev.*, 48, 703
- Stepien, K. 2006, *Acta Astronomica*, 56, 347
- Terrell, D., & Wilson, R. E. 2005, *Ap&SS*, 296, 221
- van Hamme, W. 1993, *AJ*, 106, 2096
- Wilson, R. E. 1979, *ApJ*, 234, 1054
- Wilson, R. E. 1993, in *Astronomical Society of the Pacific Conference Series*, 38, *New Frontiers in Binary Star Research*, eds. K.-C. Leung & I.-S. Nha, 91
- Wilson, R. E., & Devinney, E. J. 1971, *ApJ*, 166, 605
- Zacharias, N., Finch, C. T., Girard, T. M., et al. 2013, *AJ*, 145, 44